tures, especially in the northern sections. Heavy snows prevailed during the entire month and served as an excellent protection to grains and grasses, and their condition continues generally satisfactory. No reports of freezing have been made.—*J. W. Schaeffer*.

Wyoming.—No severe cold wave visited the State during the month and no destructive storm. Over the southeastern quarter of the State a severe storm prevailed on the 19th, but as the duration of the storm did not much exceed twenty-four hours and no cold weather accompanied it, the loss of stock was practically nothing. The snowfall of the month was very unevenly distributed over the State, the southeastern quarter receiving the greatest average.—*W. S. Palmer*.

SNOWFALL AND WATER SUPPLY IN THE ROCKY MOUNTAIN REGION.

The following extracts are taken from the snow bulletins for December, 1902, issued by the Climate and Crop Section Centers in the Rocky Mountain region:

Colorado.—For the mountain region, as a whole, the snowfall during October, November, and December has been less than normal; but as compared with the corresponding period last year there has been an excess, except on the watersheds of the Grand, White, Yampa and North Platte. Since the depths will be materially modified by the later snowfalls, the reports furnish no information as to what the water flow will be during the early part of the season. The general outlook for late irrigation, especially on the eastern and southern slopes, is much better than for several years.

Idaho.—The snowfall throughout the State during November and December has been heavy. In many sections it has been unprecedented. In a few localities it has been less than the average. Correspondents, with few exceptions, have had no hesitancy in estimating the prospective water flow for the coming crop season. Considering that the snowfall has been heavy and that in many sections it is packed and of icy character, the prospect for water is excellent without the aid of additional snow during January, February, and March.

Montana.—On the eastern slope of the Main Divide the snow was exceptionally heavy from the boundary line as far south as the Lewis and Clarke Pass; storms were frequent, and high winds drifted the snow in ravines to a depth of 50 feet in some places; these drifts are packed solid, but as no thaws have occurred they are not frozen throughout. To the immediate south of the Lewis and Clarke Pass the snows have not been so heavy; in the vicinity of Bald Butte, however, a large amount of snow is again encountered—packed drifts 25 feet in depth; about an equal fall occurred on the Missouri River side of the Main Divide in Silver Bow and Beaverhead counties, but there the winds have been light, and drifts are not general nor deep. In the mountains of Madison, Gallatin, and Park counties the fall has reached about an average, and in some localities it is a little less; it has drifted, but the drifts are not solid. In the Crazy, Big Belt, Little Belt, Highwood, and Snowy mountains the fall has been comparatively light and in some cases a little less than last year. Considering the visible supply of snow on December 31, its condition with relation to drifts, etc., and the state of the ground when the first snow fell, the conclusion is reached that the amount of conserved water very generally exceeds that at the same time last year; in Teton and northern Lewis and Clarke counties the amount will be much in excess of the average.

Nevada.—At the close of the month there was more snow on the mountains in the western part of the State than a year ago, while at the headwaters of the Humboldt River a large deficiency is reported. If average weather conditions prevail during the remainder of the winter the water flow during the coming season will probably be greater than during that of 1902.

Utah.—In all the watersheds the depth of snow in the mountains was greater at the close of December than it has been at the same time during the past three years. In the Great Salt Lake watershed the depth is about average, slightly above in the Sevier Lake watershed, and much above in the Green and Colorado rivers watersheds. The snow is fairly well drifted and very solid for this time of year. An abundant water supply for the coming crop season is already assured to the Green and Colorado rivers watersheds, and even if the precipitation be somewhat deficient during the rest of the snowfall season, a good supply may be expected in the Great Salt Lake and Sevier Lake watersheds.

Wyoming.—The storms of December over the southern half of the State increased the stock of snow, so that by the close of December about the usual depths were reported from the Laramie, Platte, Green, and Snake rivers watersheds. The snowfall over the eastern slope of the Big Horn Mountains has been very deficient; all reports from that section show that the stock of snow is at present decidedly deficient, one report stating that the present depth is the least known in that section at this season during the past ten years.

SPECIAL CONTRIBUTIONS.

STUDIES ON THE METEOROLOGICAL EFFECTS OF THE SOLAR AND TERRESTRIAL PHYSICAL PROCESSES.

By PROF. FRANK H. BIGELOW, U. S. Weather Bureau, dated December 28, 1902.

THE SEMIDIURNAL PERIODS IN THE EARTH'S ATMOSPHERE.

The double and the single diurnal periods.—The problem of accounting for the well known semidiurnal periods in the meteorological elements, barometric pressure, vapor tension or humidity, and electric potential, as observed at the surface of the earth, is still awaiting its complete solution, but since additional information on the subject has been obtained in the past few years through the different kinds of observations in the strata at higher levels above the ground, this is sufficient reason for bringing the subject before this section[1] of the American Association for the Advancement of Science. Fig. 1 shows the average curves deduced from the surface observations, as they have been repeatedly made in all parts of the tropical and temperate zones.[2]

There are two minima and two maxima, the first minimum at about 4 a. m., the second at about 4 p. m.; the first maximum at about 10 a. m., and the second at 8 to 10 p. m. If the sun is supposed to rise and set at 6 o'clock, this indicates that the diurnal atmospheric processes lag several hours behind the hour angle of the sun, just as the seasonal processes lag about forty or fifty days behind the annual temperature changes. Since this retardation occurs chiefly through the slow radiation and convection of the atmosphere, just as the annual temperature wave lags in penetrating the ground through its slow conduction, so therefore, these retardations in the diurnal elements may become the means of calculating the coefficients of conductivity and convection in the air. Now it is to be noted that while the pressure, vapor tension, and electric potential give a decided double period, the diurnal actinic radiation from the sun shows only a small midday depression, and the temperature none at all, for this is a curve with a single maximum at 3 p. m. and a minimum at 4 a. m. This suggests the problem to be resolved, namely, the occurrence of single and double diurnal periods at the same time in the lower strata of the atmosphere.

In past years, before it was recognized that the single period prevails throughout the atmosphere, except in its lowest layers, efforts were made to account for the surface double period in two ways: (1) by referring it to a dynamic forced wave involving the entire atmosphere, as was done by Lord Kelvin, and (2) by seeking to explore the possible connections between the observed waves and the manometric waves due to temperature effects in the lower strata. The first of these theories must be abandoned for weighty reasons: (1) because the double wave does not exist throughout the atmosphere, as has been stated, but is confined to the lowest strata; (2) because the double wave system breaks at the latitudes 60° north and south, and reappears in the polar zones at right angles to that system,[3] with a change in the phase of 90°; and (3) because there is no known physical principle requiring the existence of any semidiurnal forced wave system. The second theory is not satisfactory because it has been found impossible to establish any positive synchronism in its details between the temperature changes and the corresponding diurnal variations of pressure due to manometric heat effects. Dr. Julius Hann for years sought to explain the phenomena along these lines, but was obliged to abandon the attempt and to accept Lord

[1] Read before the Physics Section, B, of the American Association for the Advancement of Science at the Washington, D. C., meeting, December 28, 1902.

[2] Compare pages 120 and 121 of my paper, Eclipse Meteorology and Allied Problems, Weather Bureau Bulletin I, 1902.

[3] International Cloud Report, chapter 9.

Kelvin's dynamic wave theory for want of anything better at hand.

Like so many other scientific problems which are difficult of solution, the trouble apparently lies in the fact that the necessary observations have not been made in the right place. It was supposed that the variations noted at the ground were

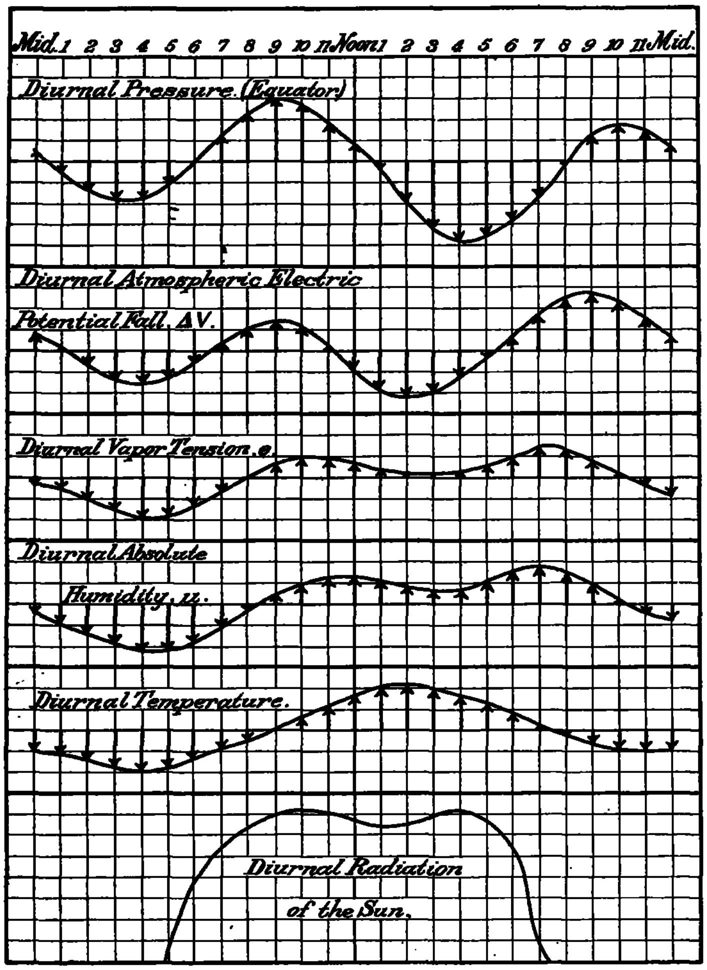

FIG. 1.—Diurnal variations of the meteorological elements in the atmosphere at the surface of the earth.

common to the adjacent strata up to considerable heights, but since meteorologists have succeeded in getting some upper air observations, this supposition turns out to be contrary to fact, as is indicated by fig. 2.

Figure 2 is based on data that are now easily accessible, and we need not quote the authorities in detail. Generally speaking, when we go upward from the surface of the ground into the atmosphere, all the double diurnal periods become single periods, and this occurs at a comparatively low elevation. Thus at the top of the Eifel Tower the double periods greatly weaken or entirely disappear, and at the elevation of one or two miles, where the convectional ascents of the aqueous vapor contents of the air cease to form cumulus clouds, only the single period seems to exist. Thus the truncated actinometer curve with serrated top, fig. 1, becomes the parabolic curve, fig. 2, even at the surface when observed in very dry atmosphere; the barometric pressure curve and the vapor tension or the absolute humidity curves synchronize with the surface temperature curve, which itself retains the single period as high up as any diurnal variations occur, and the electric potential fall becomes a single period curve at surprisingly short distances above the surface. Finally, in the temperate zones the diurnal wind components, and the magnetic deflecting vectors of the earth's magnetic field, not only agree together as vectors constituting a single system, but they also synchronize in their turning points and phases with all the other elements just mentioned. It is impracticable to go through a full description of the local exceptions to the general conditions, but they form a most interesting study for the meteorologist who keeps in mind their significance in connection with the great cosmical problems in physics. Enough has been said to show that we need to fix our attention upon the cause of the transformation of the double period into the single period in the lowest strata of the atmosphere.

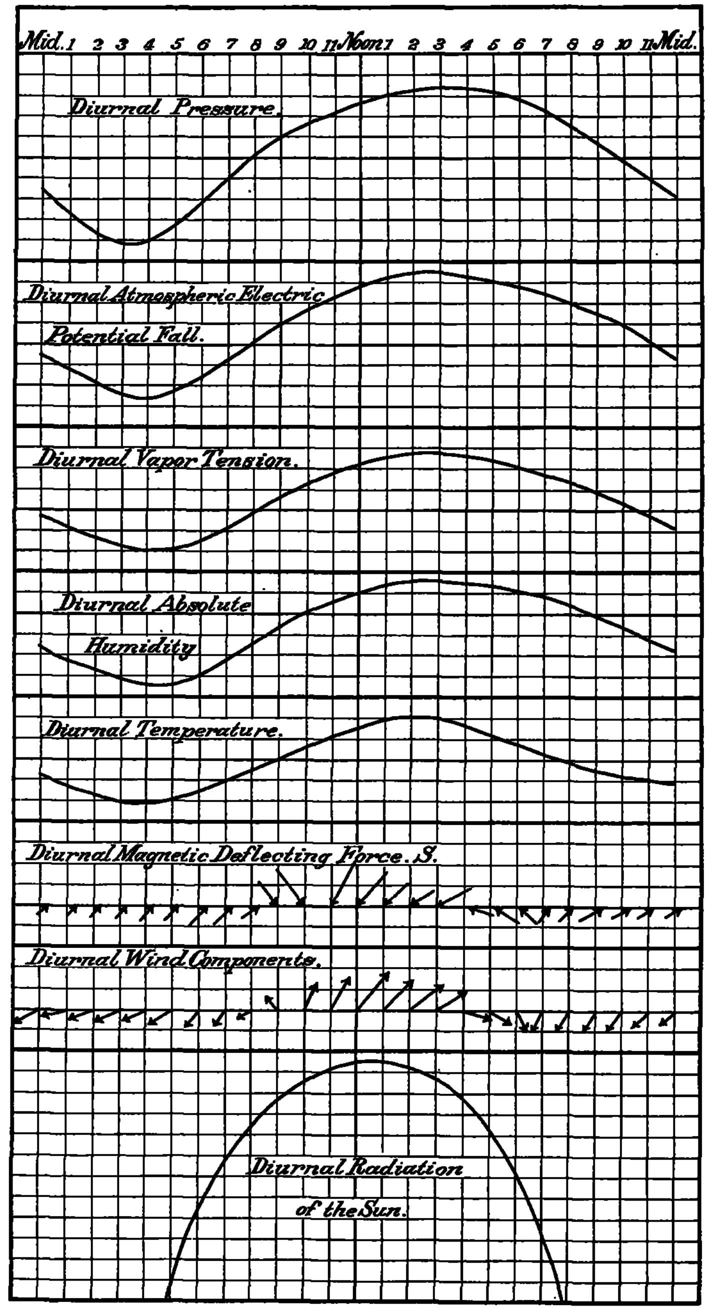

FIG. 2.—Diurnal variations of the meteorological, electrical, and magnetic elements in the atmosphere at some distance above the ground.

The solar radiation.—In my judgment there can be but one line of argument that needs to be discussed, namely, the behavior of the aqueous vapor in the presence of the solar and the terrestrial radiations. The water content of the atmosphere at any elevation is determined by the temperature and humidity of the air, and therefore the unit volumes containing equal vapor contents stand upon isothermal surfaces which span the Tropics in great arches, stretching from the north polar zone to the south polar zone. These vapor contents rise daily from lower to higher levels during the forenoon and midday, but sink back again during the afternoon and evening hours. The process is well understood and it is briefly as follows: The incoming solar radiation of short waves penetrates the earth's atmosphere, with depletion of the short waves by selective reflection, and of the long waves by the absorption in the aqueous vapor; the earth's surface is heated by the residue of the radiation, and it then radiates like a black body at its own temperature, which being relatively low limits the outward radiation to much longer terrestrial waves than the incoming solar rays. The heat received at the surface also evaporates the water of the surface, heats the lower strata, and raises the isotherms by convection currents as well as by radiation, till at the average elevation of 1000 to 2000 meters the vapor tends to condense or actually forms the visible clouds. The outgoing radiation is also depleted by aqueous vapor absorption, and this with greatly increased vigor at the level where the water vapor turns into liquid water in the first stage of condensation. We have, therefore, a daily rise and fall of the vapor in the lower atmosphere, and it is the behavior of this vapor blanket which must be studied carefully to account for the transformation of the double daily into the single daily periods described above. But it will be desirable to examine a little more fully the peculiarities of the solar and the terrestrial radiations before going on to our conclusions.

Let $J =$ the radiation from any single spectral line of a black body.

$J_m =$ the maximum radiation occurring in the spectrum of a black body.

$J_o =$ the total radiation throughout the whole spectrum from a unit surface of a black body.

λ = the wave length corresponding with J.

λ_m = the maximum wave length corresponding with J_m.

$T_1 =$ the absolute temperature of the emitting body.

$T_2 =$ the absolute temperature of the absorbing body.

A = the solar constant or the value of J_o at the distance of the earth from the sun.

$R =$ the radius of the sun in kilometers.

d = the distance of the earth from the sun in kilometers.

Then we obtain by the Wien-Paschen formulæ in units of gram calories per cm^2 per second, per minute, and per day, respectively, the following equations:

Radiation function in the normal spectrum.

I. Radiation from a single spectral line in gram calories per cm^2.

$$J = \frac{dJ_o}{d\lambda} = c_1 \lambda^{-5} 10^{-\frac{c_2 M}{\lambda T}}$$

$$= \frac{9.292 \times 10^3}{\lambda^5 \left(10^{\frac{6277.4}{\lambda T}}\right)} \frac{\text{Gr. Cal.}}{cm^2.\ \text{second.}}$$

$$c_1 = \frac{1.277 \times 10^{-12} c_2^4}{6} = \frac{1.277 \times 10^{-12} (14455)^4}{6} \qquad \text{Logarithms.}$$

$$= 9.292 \times 10^3 \text{ per sec.} \qquad 0.96811$$

$$= 5.575 \times 10^5 \text{ per min.} \qquad 5.74626$$

$$= 8.028 \times 10^8 \text{ per day.} \qquad 8.90462$$

$$c_2 = 5 \times 2891 = 14455 \qquad 4.16002$$

$$c^2 M = 14455 \times 0.43429 = 6277.4 \qquad 3.79780$$

II. Total radiation of a black body.

$$J_o = 1.277 \times 10^{-12} (T_1^4 - T_2^4) \frac{\text{Gr. Cal.}}{cm^2.} \text{ per sec.} \qquad 8.10619-20$$

$$= 7.662 \times 10^{-11} (T_1^4 - T_2^4) \quad \text{" per min.} \qquad 9.88434-20$$

$$= 1.1033 \times 10^{-7} (T_1^4 - T_2^4) \quad \text{" per day.} \qquad 13.04270-20$$

The solar constant $A = J_o \times \frac{R^2}{d^2}$

$$= J_o \times 2.1643 \times 10^{-5} \text{ per min.} \qquad 5.33532-10$$

Radius of the sun. $R = 695\,500$ kilometers. 5.84230

Distance of earth from sun. $d = 149\,500\,000$ kilos. 8.17464

$$A = 7.662 \times 10^{-11} (T_1^4 - T_2^4) \times 2.1643 \times 10^{-5}$$

$$= 1.6583 \times 10^{-15} (T_1^4 - T_2^4) \text{ per min.} \qquad 5.21966-20$$

III. Maximum radiation in a normal spectrum.

$$J_m = \frac{c_1\, 5^5}{c_2^5\, 10^{5M}} T^5 = \frac{5.575 \times 10^5 \times 5^5}{(14455)^5\, 10^{2.17146}} T^5$$

$$= 3.1004 \times 10^{-16}\, T^5 \text{ per sec.} \qquad 4.49141-20$$

$$= 1.8602 \times 10^{-14}\, T^5 \text{ per min.} \qquad 6.26956-20$$

$$= 2.6787 \times 10^{-11}\, T^5 \text{ per day.} \qquad 9.42792-20$$

IV. $\frac{J_m}{J_o} = \frac{3.1004 \times 10^{-16}\, T^5}{1.277 \times 10^{-12}\, T^4} = 2.4289 \times 10^{-4}\, T.$ 6.38522—10

V. $\lambda_m T = 2891.$ 3.46105

(Eclipse Meteorology and Allied Problems, page 164.)

From formula IV we have the following equation:

$$J_m = 0.00024\ T \times J_o.$$

Hence, for

$T = 100°$; $J_m = 0.024\ J_o$; and $J_o = 42\ J_m$.
$T = 1000°$; $J_m = 0.24\ J_o$; $J_o = 4.2\ J_m$.
$T = 10000°$; $J_m = 2.4\ J_o$; $J_o = 0.42\ J_m$.

That is to say for low temperatures the total radiation J_o is much greater than the maximum radiation J_m, but for high temperatures J_o becomes less than J_m. Since J_o is the integral of the area of the curve of energy intensity, it should evidently be greater than J_m under all circumstances, but the fact that by this formulæ (IV) it becomes less for temperatures above 4119° seems to indicate that there may be something wrong in the deduction of the formulæ III for J_m and II for J_o, from which IV for $\frac{J_m}{J_o}$ was derived. These formulæ and constants have been tested by numerous experiments, and they appear to be satisfactory for temperatures up to about $T = 1500°$. It is noted that there is a tendency for the coefficients c_1, c_2 to change in passing from low temperatures and long wave lengths ($T = 273°$ to 750°) to higher temperatures and longer wave lengths ($T = 750°$ to 1500°). Compare page 164, Eclipse Meteorology. At all these temperatures the ratio J_m/J_o seems to be normal, but at the higher solar temperatures this is no longer the case. It may therefore be the fact that the extrapolation to such temperatures as $T = 7000°$ to 8000° is not allowable without a considerable change in these constants, or even in the exponents of the formula. It may be that there is a breakdown in the molecular structures of so-called black bodies at very high temperatures, which causes them to emit quite different spectra curves from those which we have computed by these formulæ. If this point of view is correct, it will be necessary to move very cautiously in computing the value of the solar constant, at the distance of the earth, from formulæ deduced in our laboratories and applied to the sun as to a common black body.

By means of these formulæ we construct the solar and terrestrial curves for various temperatures for the incoming radiation of the sun, supposing it to range from 8000° to 3000°; also for the outgoing radiation from the earth with a range of from 383° to 198° absolute temperature. The corresponding coordinates are given in Tables 1 and 2; they are also plotted graphically on fig. 3 for the sun, and on fig. 4 for the earth. On the solar curve for $T = 6000°$ is placed Professor Langley's energy curve as derived by the bolometer observations.

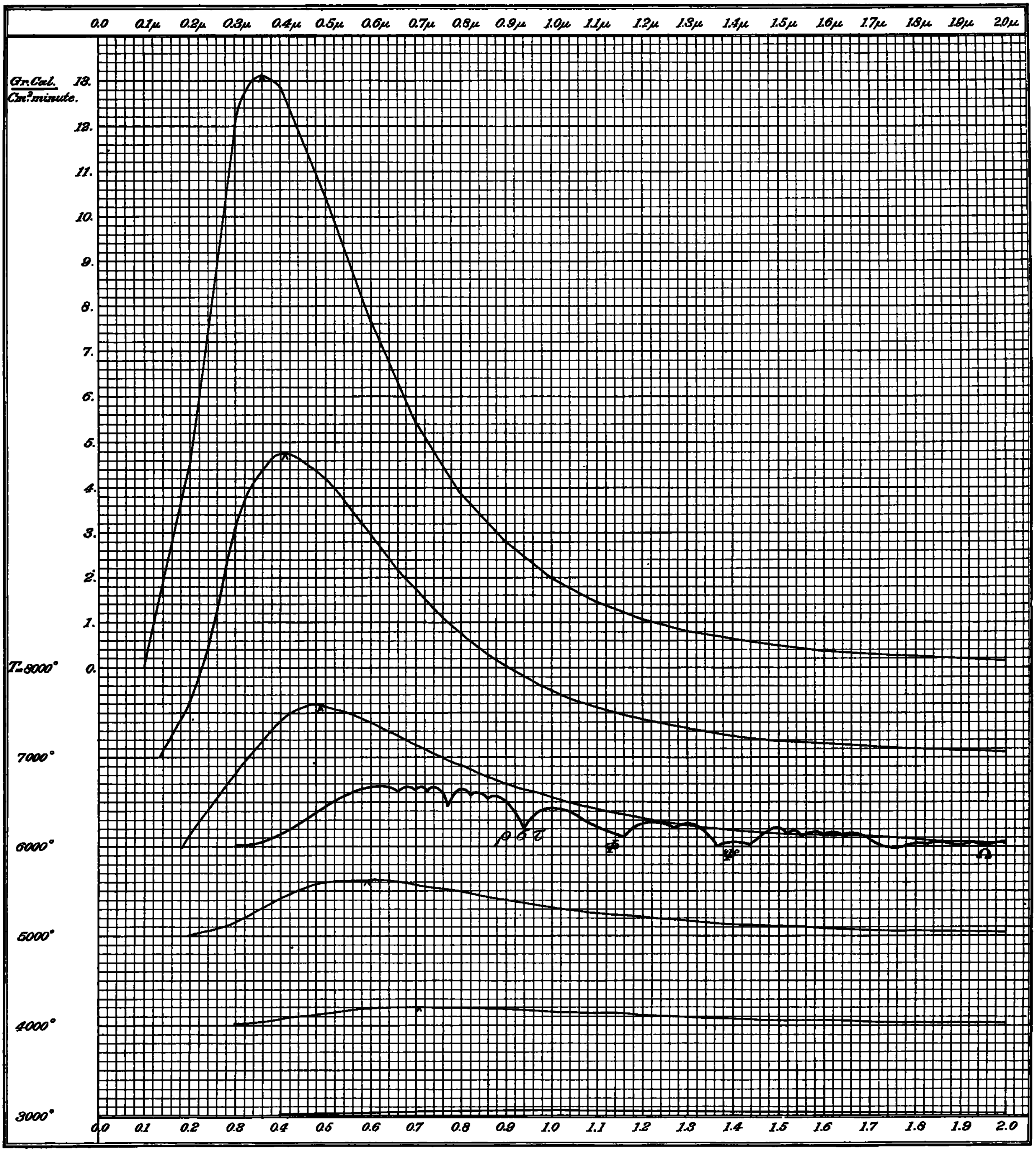

FIG. 3.—Energy spectra at solar temperatures reduced to the distance of the earth.

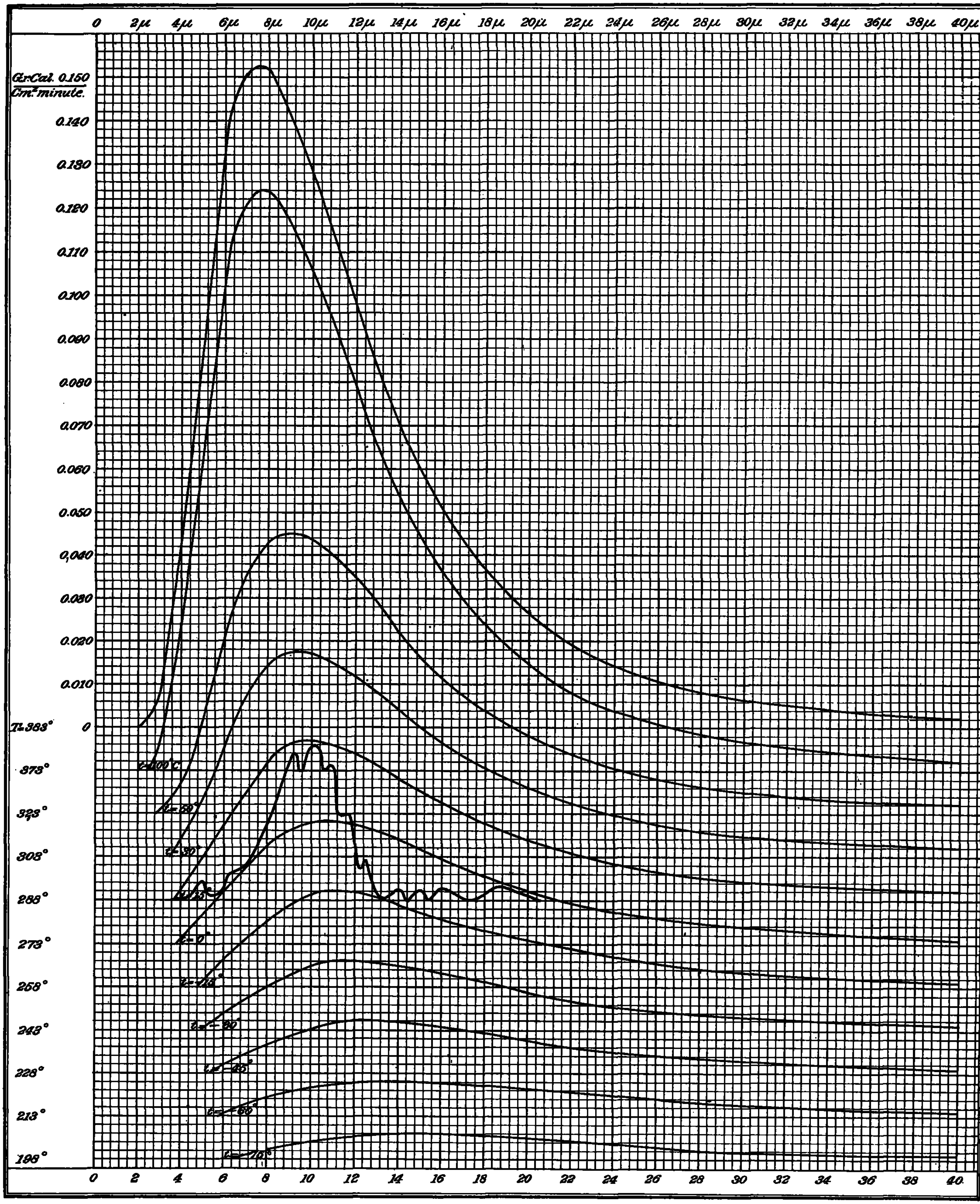

FIG. 4.—Energy spectra at terrestrial temperatures.

TABLE 1.—*Energy spectra at solar temperatures reduced to the distance of the earth, expressed in units of gram calories per square centimeter per minute.*

T.	8,000°	7,000°	6,000°	5,000°	4,000°	3,000°
λ = 0.0μ..	0.00					
0.1..	0.02	0.00	0.00			
0.2..	4.50	1.24	0.22	0.02		
0.3..	12.03	5.09	1.62	0.32	0.03	
0.4..	12.87	6.75	2.85	0.86	0.14	0.01
0.5..	10.41	6.21	3.12	1.19	0.28	0.03
0.6..	7.64	4.96	2.80	1.25	0.38	0.05
0.7..	5.43	3.76	2.30	1.15	0.40	0.07
0.8..	3.85	2.79	1.81	0.99	0.40	0.09
0.9..	2.81	2.06	1.41	0.82	0.37	0.10
1.0..	1.98	1.53	1.09	0.67	0.33	0.10
1.1..	1.45	1.15	0.84	0.54	0.28	0.09
1.2..	1.08	0.87	0.65	0.44	0.24	0.09
1.3..	0.81	0.66	0.51	0.34	0.20	0.08
1.4..	0.62	0.52	0.40	0.28	0.17	0.07
1.5..	0.48	0.40	0.32	0.23	0.14	0.06
1.6..	0.39	0.32	0.26	0.19	0.12	0.06
1.7..	0.30	0.25	0.21	0.16	0.10	0.05
1.8..	0.23	0.20	0.17	0.13	0.09	0.04
1.9..	0.19	0.16	0.14	0.11	0.07	0.04
2.0..	0.15	0.13	0.11	0.09	0.06	0.03
2.5..	0.06	0.05	0.05	0.04	0.03	0.02
3.0..	0.03	0.03	0.02	0.02	0.02	0.01
J_m...	13.19	6.77	3.13	1.26	0.41	0.10
λ_m...	0.36μ	0.41μ	0.48μ	0.58μ	0.72μ	0.96μ
A ...	6.79	3.98	2.15	1.04	0.43	0.13

$$J = \frac{5.575 \times 10^5}{\lambda^5 \left(10^{\frac{6277.4}{\lambda T}} \right)}$$

J in units $\frac{\text{Gr. Cal.}}{cm^2.\ \text{minute.}}$

TABLE 2.—*Energy spectra at terrestrial temperatures, expressed in units of gram calories per square centimeter per minute.*

T.	383°	373°	323°	303°	288°	273°	258°	243°	228°	213°	198°
λ = 2μ..	0.000										
3 ...	.008	.006	.001								
4 ...	.044	.034	.007	.004	.002	.001					
6 ...	.134	.113	.041	.025	.017	.011	.006	.004	.002	.001	.000
8 ...	.152	.134	.063	.044	.032	.023	.015	.010	.006	.004	.002
10 ...	.128	.116	.064	.047	.037	.028	.021	.015	.010	.006	.004
12 ..	.097	.089	.055	.042	.034	.027	.021	.016	.012	.008	.005
14 ...	.070	.065	.042	.034	.028	.024	.019	.015	.011	.008	.006
16 ...	.050	.047	.032	.027	.023	.019	.016	.013	.010	.007	.006
18 ...	.036	.034	.025	.021	.018	.016	.013	.011	.009	.007	.005
20 ...	.027	.025	.019	.016	.014	.012	.011	.009	.007	.006	.005
22 ...	.019	.018	.014	.012	.011	.010	.009	.007	.006	.005	.004
24 ...	.015	.014	.011	.010	.009	.008	.007	.006	.005	.004	.003
26 ...	.011	.011	.008	.007	.007	.006	.005	.005	.004	.003	.003
28 ...	.008	.008	.007	.006	.005	.005	.004	.004	.003	.003	.002
30 ...	.007	.006	.005	.005	.004	.004	.004	.003	.003	.002	.002
32 ...	.006	.005	.004	.004	.004	.003	.003	.003	.003	.002	.002
34 ...	.004	.004	.003	.003	.003	.002	.002	.002	.002	.002	.001
36 ...	.003	.003	.003	.003	.003	.002	.002	.002	.002	.001	.001
38 ...	.003	.003	.002	.002	.002	.001	.001	.001	.001	.001	.001
40 ...	.002	.002	.002	.002	.002	.001	.001	.001	.001	.001	.001
J_m...	.153	.134	.065	.048	.037	.028	.021	.016	.011	.008	.006
λ_m...	7.55μ	7.75μ	8.95μ	9.54μ	10.0μ	10.6μ	11.2μ	11.9μ	12.7μ	13.6μ	14.6μ
J_o...	1.649	1.483	0.834	0.646	0.527	0.426	0.340	0.267	0.207	0.158	0.118

Remarks on the solar constant.—This exhibit suggests some comments on the depletion of the short waves by selective reflection or scattering, and of the long waves through absorption by aqueous vapor. According to F. W. Very's discussions,[4] the selective depletion and absorption in the solar atmosphere of the radiation from the photosphere, may be due to four cooperating causes: (1) to a considerable extension of finely divided solar material in the outer corona to the distance of about one radius; (2) to scattering upon the molecules and other very fine particles especially in the inner corona; (3) to the passage through a columnar structure having different coefficients of transmission; (4) to emission from the uneven granular surface of the photosphere radiating at different temperatures. According to Professor Schuster's recent paper,[5] the depletion effect can be suitably explained by "placing the absorbing layer sufficiently near the photosphere and taking account of the radiation which this layer, owing to its high temperature, must itself emit." It is not proper to regard the radiating photosphere as of a single temperature, but as ranging somewhat, though not through many hundred degrees, with the depth of the strata, the lower being hotter; the coefficients of transmission vary with the wave length, and with the extent of path traversed, and therefore with the marginal distance of the ray from the center of the sun, the marginal transmission being rendered more efficient by early sifting out of the rays that are easily absorbed by the existing material. In the present stage of the problem it is difficult to assign the exact percentage of absorption due to the sun's atmosphere taken as a whole, and, from similar considerations, the percentage due to the absorption in the earth's atmosphere remains in doubt. Hence, it is not easy to derive the true temperature of the sun's radiating surface, even taken as an integral. Comparing the Langley curve with the energy curve for 6000°, it suggests that the short wave ordinates imply a temperature of about 5000°, but that the long waves at the same time require a temperature of rather more than 7000°, especially as indicated by those from 1.5μ to 1.7μ. Dr. Niles Ekholm[6] attempts to reconcile these conflicting facts by assigning a system of varying temperatures, $T = 5226 + 1000\lambda$, increasing with the wave length, till T equals 7226° for $\lambda = 2.0\mu$. While this brings the two curves nearer together throughout their extent there are two difficulties yet to be overcome: (1) the sun's atmosphere depletes short waves most in its lower strata, while the long waves escape more readily, some of them apparently quite unaffected. Since the short waves by Ekholm's hypothesis are assigned to lower temperatures, this implies that they are emitted only by the higher strata in the sun's atmosphere, and therefore it follows that they do not register the temperature of the photosphere at all accurately. Furthermore, the temperature in the solar atmosphere above the photosphere can not have a range of 2000°. (2) If the long waves which actually pass through both the atmospheres of the sun and the earth do possess energy ordinates corresponding to temperatures as as high as 7200° to 7500° they could not have been generated at all except at such high temperatures as these, and they in fact become an important index for determining the efficient photospheric temperature. It seems to me that since the long wave radiation at 1.5μ to 1.7μ requires a temperature of nearly 7500° we must let this fact control our conclusions, rather than depend upon the deductions to be derived from estimated percentage depletions of the short waves of the spectrum. It is noted that this gives a result nearly in harmony with the temperature $T = 7535°$, which was assigned by me to the photosphere from meteorological considerations (Eclipse Meteorology, page 81). Thus, in determining the hydrogen gas constant at the sun, we have,

$$R = \frac{p_o}{\rho_o T_o} = \frac{10333\ \text{(earth)}}{0.089996 \times 273°} = \frac{285185\ \text{(sun)}}{0.089996 \times 7535°} = 420.55.$$

Since p (sun) $= 10333 \times 27.6 = 285185$, it follows that $273° \times 27.6 = 7535°$, is the absolute temperature of the photosphere.

It was found that the rate of change of temperature from the photosphere vertically outward seems to be rather small,

$$\frac{dT}{dt} = -0.013° \text{ per 1000 meters, that is, about 300° from the}$$

the photosphere to the top of the inner corona, and this would indicate that we do not have in the sun's upper atmosphere such extremes of temperature to deal with as Ekholm's formula requires. But if we assign so high a temperature as 7535° to the photosphere, the depletion by scattering as shown by the diagrams of fig. 3 must be much greater than usually assigned, as is evident by comparing the curves, and we must also infer that the solar constant is really large in order to correspond to this temperature, namely, about 4.0 gram calories per square centimeter per minute at the outer limits of the earth's atmosphere.

[4] Atmospheric Radiation, F. W. Very, Bulletin G, Weather Bureau, 1900. The solar constant, F. W. Very, Monthly Weather Review, August, 1901. The absorption power of the solar atmosphere, F. W. Very, Astrophysics, September, 1902.

[5] The solar atmosphere, Arthur Schuster, Astrophysics, January, 1903.

[6] Ueber Emission und Absorption der Wärme und deren Bedeutung für die Temperatur der Erdoberfläche, Meteorologische Zeitschrift, January, 1902.

In the earth's atmosphere selective scattering takes place on the molecules of the constituents of the air, especially in the lower strata, and absorption occurs throughout the shell occupied by the aqueous vapor, but also chiefly in the lower strata. It is again difficult to assign the relative parts due to scattering and absorption, respectively. Prof. F. W. Very contends that the aqueous vapor of the higher strata first attacks the incoming radiation and depletes it very considerably and thus raises the temperatures of the high strata. Our international cloud observations, and the direct temperature readings in balloon ascensions seem to sustain this view. But Ekholm argues from the heat content of the atmosphere, assuming the solar constant of 3.0 calories, as follows:

		Calories.
Solar constant = 3.0 calories per minute..		3.00
40 per cent absorbed = 0.40 × 3.0........		1.20
Inward.—(1). The air receives one-fourth of this and holds it..................	$\frac{432}{1440}$	= 0.30
(2). Conduction to be neglected		0.00
(3). Convection to be neglected		0.00
Outward.—(4). From vaporization of aqueous vapor	$\frac{164}{1440}$	= 0.11
(5). Radiation from earth = 50 per cent, where the surface receives ⅓ of 3.00 = 1.00.............	$\frac{98}{1440}$	= 0.07
Total received per minute	$\frac{694}{1440}$	= 0.48

This corresponds to a mean temperature of the air 8.6° C., while the observed mean temperature is —17.0° C., or too low by 25.6° C. Ekholm says: "It follows that the supposed great absorption of heat by the atmosphere does not take place. But we must admit that the atmosphere absorbs directly only a small fraction of the insolation, and that it is chiefly warmed indirectly from the earth's surface." In a word, the aqueous bands absorb some little heat, while the air is nearly diathermanous to the rest of the energy spectrum. I shall, however, venture to raise the following inquiry. Ekholm seems to have assigned certain percentages for absorption, which of course are in the nature of a conjecture so long as the solar temperature remains in doubt, and a part of the discrepancy between the mean temperature of the earth's atmosphere as observed and as deduced from the solar constant, may be explained in that way. But, furthermore, he seems to compute the total energy received on the basis of a twenty-four hour radiation, and to have made no allowance for the fact that the earth receives only twelve hours of sunshine. The solar constant per minute when applied to the residual temperature of the atmosphere should have this fact included, but I am not able to decide from Ekholm's paper whether this was done in fixing upon his percentages. I infer, in any event, that the common procedure of extrapolating to the value of the solar constant on the outer atmosphere by using the spectrum throughout its entire length assigns too much weight to the short waves, which certainly suffer severely from scattering, and that on the other hand the few long undepleted waves 1.5μ to 1.7μ which are neither absorbed nor scattered, form the proper basis for deducing the true solar constant. Judging from these data it is probably not far from 4.0 calories, and the temperature of the photosphere must be about 7500°.

The terrestrial radiation.—If the energy line plotted on curve T = 288° of fig. 4 represents the observed earth's transmission through the air as described by Very (see Bulletin G, page 124), it seems to be in conflict with the view that the earth radiates like a black body of low temperature. The strong absorption from $\lambda = 4\mu$ to 8η is evidently due to aqueous vapor, but the much greater absorption area from $\lambda = 12\eta$ to 40μ is apparently not to be attributed to the same cause. It seems to me much more probable that the earth does not radiate these long waves like a black body, but is really deficient in them and emits freely only the waves from $\lambda = 4\mu$ to 12μ. On the other hand Ekholm[7] has drawn the curve from 11μ to 20μ in quite a different manner, by extrapolating from Langley's corrected observations on the moon's radiation, so as to follow the normal energy curve much more closely.

Since no observations exist to determine this point it may still be left open to doubt whether the waves are emitted or not. If they are really emitted, then the air must have other absorbing constituents that have not yet been attributed to it to satisfy Very's curve.

We may now study briefly the effect of the earth's long-wave radiation upon the meteorological elements, and explain the occurrence of the double periods at the surface and single periods at the cumulus cloud levels. If the scattering effect throws back into space a considerable percentage of the incoming radiation so that it does not reach the earth at all, on the other hand the absorption by the aqueous vapor of the terrestrial long waves tends to efficiently conserve the earth's temperatures which are high relatively to that of the interplanetary space, and at the same time it generates a series of interesting physical processes which can be described with at least approximate correctness. A field of research of unusual importance and interest is here presented to the meteorologist. The discussion of the temperature and vapor pressure observations which have been taken in the United States. during the past thirty years, is now going on at the Weather Bureau, and we hope to be able to make some further contributions to this subject by extending to the further study of the cloud formations those thermodynamic processes which were applied in a few cases in the International Cloud Report.

We adopt the hypothesis that aside from a moderate absorption of solar radiation by the aqueous vapor in the atmosphere, the waves pass through it unimpeded, except by scattering, which turns back a considerable percentage into space. The energy of the portion reaching the earth's surface is expended in raising its surface temperature. This increases from early morning till midday, with a lag of about two hours due to the slowness of propagation of the physical effects into the atmosphere, and then declines in the reverse order till midnight. The earth radiates in the forenoon something like a black body of gradually increasing temperature, the longest waves being possibly excluded, though their energy has not yet been mapped out beyond $\lambda = 12\mu$. The aqueous vapor depletes the outgoing radiation strongly in the waves 4μ to 8μ and probably from 12μ to 20μ. It is especially to be noted that when water vapor turns to liquid water in cloud condensation the power of aqueous absorption is increased a hundred fold, and thus the generation of clouds forms at the same time an absorbing screen at the cumulus level which practically confines the radiation emanating from the land and the ocean to the strata within a mile or two above the earth's surface. Carbon dioxide, CO_2, can absorb only its own peculiar rays, and as these constitute only a small portion of the spectrum their total effect is small compared with that of the aqueous vapor.

Explanation of the formation of the two types of diurnal periods.—Let us illustrate the formation of the double diurnal period at the earth's surface and the single period in the cumulus level by considering the behavior of the absolute humidity, that is the number of grams of water vapor per cubic centimeter. The first diurnal effect of the radiation from the earth is to raise the vapor content of the atmosphere from the low level

[7] Ueber Emission und Absorption der Wärme und deren Bedeutung für die Temperatur der Erdoberfläche. Nils Ekholm, Met. Zeit., November, 1902.

occupied by it at night to a higher level during midday. This absorbing screen of water vapor, visible or not, rises and falls once daily through 1000 or 2000 meters, taken as a whole. While the warm air rises by convection from the surface to the level of 1500 meters, the vapor rises with it and endeavors to saturate the unit volumes of the higher strata at the prevailing lower temperatures, the depleted lower volumes being *partially filled up again by fresh evaporation* from the water and land surfaces. Thus, in fig. 5, which represents the humidity

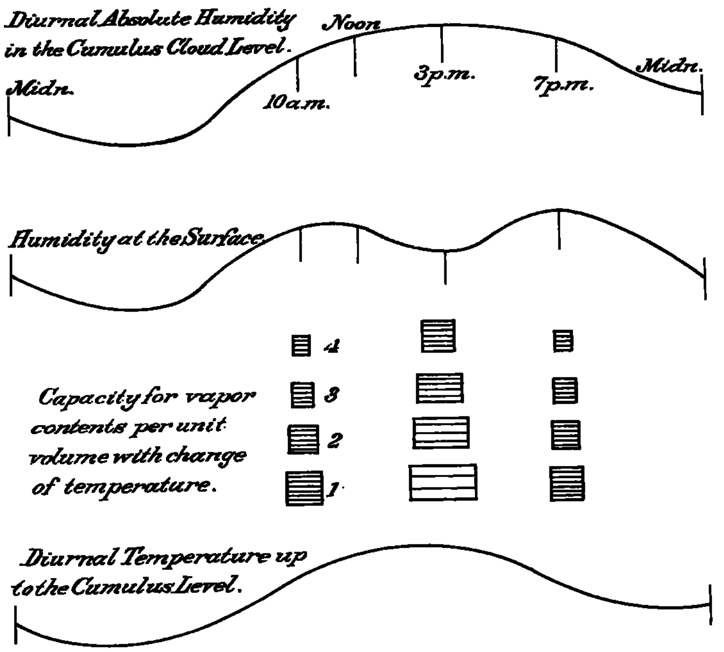

FIG. 5.—Illustrating the formation of the double and single diurnal periods of the absolute humidity.

variations at the earth's surface and at the cumulus level, and the temperature changes at all levels up to a moderate elevation of probably 3000 or 4000 meters, we may consider the behavior of the successive volume capacities arranged in vertical lines. There is a decrease in actual temperature with the elevation, and therefore the saturated unit-volume content decreases. The vapor sheet rises to higher levels, and this, together with the fresh supply by evaporation from the surface, can refill the depleted volume again, especially during the forenoon hours. After the noon hour the continued increase of temperature gives rise to larger vapor capacity per unit-volume, represented by larger areas on the diagram which are shaded more thinly and decrease upward in dimensions. But while the rising vapor sheet keeps the upper volumes filled, the lower, which are drained by the ascension of the water vapor, can not be supplied by evaporation at the surface at a sufficiently rapid rate to keep them full, because the prevailing surface moisture has been taken up at an earlier hour. The same remarks are true for the relative humidities. The result is that the upper volumes are always full, or relatively full, and have an increasing actual content up to the early afternoon, about 2 p. m., so that the diurnal curve at some distance above the ground has a single maximum and minimum as observed. On the other hand, while the 10 a. m. surface volumes are kept filled, or relatively filled, they are actually depleted in the afternoon and are not replenished by evaporation up to the original relative humidity of the morning, and therefore the curve shows a depression in the early afternoon, and is doubly periodic. The second maximum at the surface is due to a reversal of this process as the vapor settles back slowly to the ground during the afternoon and night. The additional lag of the evening maximum, being four hours in the evening to about 10 p. m., is due to the slow cooling of the ground after sunset, which continues to be a source of heat for several hours, and the slow conductivity of the heated atmosphere, which retains its heat even longer than the ground after the sun has set. This theory, if pursued into quantitative details will evidently account for the entire series of observed phenomena, and I hope to continue the study of this subject with such data as are now at the disposal of meteorologists. If we compare the areas of the complete actinometer curve of fig. 2 with that of fig. 1, as it is observed, the truncated portion must represent the heat energy that has been converted into work in carrying out these physical processes. Like an engine indicator-diagram, the difference between these curves can be translated as a function of the process concerned in the double diurnal periods in the lower strata, and thus become an important means of studying this function in the free atmosphere. If we could have suitable observations of the several elements at all levels up to 1 or 2 miles high, it would be a comparatively easy problem to discuss to a conclusion. At present the serious difficulty is to secure the necessary data since we must resort to more or less indirect methods.

The remaining elements may be treated for the change of period in a very few words. Analyzing the diurnal barometric pressure by volume contents we see that with the heating of the lower strata the denser air of night is replaced by contents of lower density after midday; taking into account the lag, the lower volumes are depleted and the upper are filled relatively, thus producing the two types of periods. This is entirely analogous to the barometric pressures of winter and summer wherein the summer pressures are lower at the surface of the earth, but greater at some such level as 1500 to 2000 meters, the summer pressure corresponding to that of the diurnal pressure in the afternoon. The later diurnal lag in the evening to 10 o'clock is a function of the cooling of the lower atmosphere by convection and radiation, and the settling back of the vapor sheet to the surface of the ground. The details of this phenomenon, as given in chapter 9 of the International Cloud Report, can all be shown to be in accord with this view, especially since the efficient vapor action caused by the lifting of the vapor sheet through radiation occurs outside the polar zones, and is greatest in the Tropics. It should be admitted that we do not yet understand the cause of the change of the phase of the diurnal barometric pressure which takes place in the polar zones. It is inferred from these considerations that since the double diurnal period is confined to a thin sheet near the surface, and does not extend throughout the atmosphere, Lord Kelvin's theory of a dynamic forced wave is not available for explaining this phenomenon. Dr. Hann's difficulties regarding the synchronism of the temperature with the diurnal barometric pressure will also probably disappear, because the local behavior of the vapor sheet in dry and moist localities will impose strongly modifying conditions upon the efficient action of the surface temperatures in respect to the two types of periods.

The fact that water vapor is a very powerful absorbent of given waves, and that this occurs chiefly in the cumulus level and not at the ground, indicates that it is the cloud temperatures which must be studied for synchronism rather than those of the free air near the surface of the earth. It is evident that a large task in observations must be executed by meteorologists before the details of these processes can be satisfactorily worked out.

From what was written in my report on Eclipse Meteorology and Allied Problems regarding the ionization of the atmosphere and the formation of electric potential, it becomes evident that temperature changes occur when the molecular structure of the aqueous vapor of the atmosphere undergoes modification by breaking up, at least temporarily, into atoms and ions. Since the transition from water vapor to liquid, in cloudy condensation, marks a sensitive condition, and since it is just at this instant that the terrestrial (not solar) radiation is most absorbed, therefore all the conditions favor an excessive generation of ions and a change in the electric potential gradient. The fact that this element follows strictly the two type periods seen in the humidity and the barometric pressure makes it necessary that the absorption of energy and the ionization should be resultant functions occurring together in one general process. I believe that all the complex details observed regarding atmospheric electricity will be explained along these lines. Finally, in fig. 2, it is indicated that the diurnal deflecting wind components and the magnetic deflecting vectors of the earth's field are in close synchronism throughout the twenty-four hours, but by comparing them with the diurnal radiation of the sun and the temperature it is seen that they are simply parts of the single period system which is common to all strata of the atmosphere, except the lowest, in the three elements described, namely, the barometric pressure, vapor tension, and electric potential gradients. We infer, then, that since the double period depends strictly on the convectional rise and fall of the vapor sheet, the magnetic field is primarily more closely connected with the effects of the solar direct radiation throughout the atmosphere. What we lack in this connection is a series of observations to determine the variation of the magnetic components in the higher strata, which I doubt not will be found to be similar to those at the surface. In all respects it is evident that observation in the lower cloud region is as much demanded by the magnetician as by the meteorologist, to determine the subtle cross connections between the gaseous contents of the atmosphere and the electrical and the magnetical variations. But it seems to me very probable that the magnetic diurnal variations are due to a set of physical processes induced by the terrestrial radiation in the lower atmosphere. This may explain the fact that the incoming solar radiation does not seem to be the cause of the ionization which apparently precedes the generation of the electric and the magnetic disturbing forces. If this problem can be solved in the free air, it will probably also contribute important facts regarding our general knowledge of the relations between matter and ether. It is especially desirable to note that the facts which are now known indicate that the diurnal variation of the magnetic field of the earth is strictly a meteorological effect in the atmosphere, caused by the solar-terrestrial radiation, and that the order of production is (1) temperature, (2) electric potential, (3) magnetic deflection, somewhat as explained in Bulletin I, Eclipse Meteorology and Allied Problems.

HAWAIIAN CLIMATOLOGICAL DATA.

By CURTIS J. LYONS, Territorial Meteorologist.

GENERAL SUMMARY FOR DECEMBER, 1902.

Honolulu.—Temperature mean for the month, 70.8°; normal, 71.8°; average daily maximum, 75.9°; average daily minimum, 66.0°; mean daily range, 9.9°; greatest daily range, 18°; least daily range, 6°; highest temperature, 80°; lowest, 61°.

Barometer average, 29.938; normal, 29.970; highest, 30.11, 29th; lowest, 29.73, 10th; greatest 24-hour change, that is, from any given hour on one day to the same hour on the next, 0.10; lows passed this point on the 2d, 10th, and 21st; highs on the 5th, 14th, and 29th.

Relative humidity average, 77.7 per cent; normal, 75.7 per cent; mean dew-point, 63.1°; normal, 63.1°; mean absolute moisture, 6.39 grains per cubic foot; normal, 6.32 grains. There was an unusual period of low dew-point during the last ten days of the month.

Rainfall, 10.20 inches; normal, 3.92 inches; rain record days, 18; normal, 16; greatest rainfall in one day, 3.20, on the 22d; total at Luakaha, 26.50 inches; normal, 10.24 inches; total at Kapiolani Park, 7.81 inches; normal, 3.55 inches.

The artesian well level rose during the month from 33.90 to 34.57 feet above mean sea level. December 31, 1901, it stood at 34.05. The average daily mean sea level for the month was 9.87 feet, the assumed annual mean being 10.00 feet above datum. For December, 1901, it was 10.26. For the year 1902, 9.85. For the previous year, 10.17.

Rainfall data for December, 1902.

Stations.	Elevation.	Amount.
HAWAII.		
HILO, e. and ne.	*Feet.*	*Inches.*
Waiakea	50	15.40
Hilo (town)	100	15.48
Kaumana	1,250	....
Pepeekeo	100	19.15
Hakalau	200	19.00
Honohina	300	19.74
Puuohua	1,050	34.84
Laupahoehoe	500	....
Ookala	400	23.48
HAMAKUA, ne.		
Kukaiau	250	24.99
Paauilo	750	29.25
Paauhau (Mill)	300	19.00
Honokaa (Muir)	425	19.64
Honokaa (Meinicke)	1,100	24.90
Kukuihaele	700	17.92
KOHALA, n.		
Niulii	200	14.87
Kohala (Mission)	521	13.62
Kohala (Sugar Co.)	235	15.04
Puakea Ranch	600	10.43
Hawi	600	....
Puuhue Ranch	1,847	13.29
Waimea	2,720	16.84
KONA, w.		
Kailua	950	....
Holualoa	1,350	5.01
Kealakekua	1,580	6.83
Napoopoo	25	3.50
Hoopuloa	1,650	3.78
KAU, se.		
Kahuku Ranch	1,680	4.69
Honuapo	15	5.38
Naalehu	650	5.47
Hilea	310	8.20
Pahala	850	5.08
Moaula	1,700	....
PUNA, e.		
Volcano House	4,000	10.79
Olaa, Mountain View (Russel)	1,690	20.95
Kapoho	110	....
Pahoa	700	17.00
MAUI.		
Lahaina	200	5.37
Waiopae Ranch	700	....
Kaupo (Mokulau), s	285	10.18
Kipahulu, s	300	14.26
Nahiku, ne	850	33.83
Nahiku	1,600	....
Haiku, n	700	14.70
Kula (Erehwon), n	4,500	9.93
Kula (Waiakoa), n	2,700	5.31
Puuomalei, n	1,400	18.59
Haleakala Ranch	2,000	21.82
Wailuku, ne	200	7.96

Stations.	Elevation.	Amount.
OAHU.	*Feet.*	*Inches.*
Punahou (W. B.), sw	47	10.20
Kulaokahua (Castle), sw	50	8.94
Makiki Reservoir	120	9.17
U. S. Naval Station, sw	6	11.56
Kapiolani Park, sw	10	7.81
Manoa (Woodlawn Dairy), c.	285	15.75
Manoa (Rhodes Gardens)	300	21.02
School street (Bishop), sw	175	....
College Hills	175	9.76
Insane Asylum, sw	30	10.43
Kamehameha School	75	10.94
Kalihi-Uka, sw	450	21.35
Nuuanu (W. W. Hall), sw	50	10.38
Nuuanu (Wyllie street)	250	13.28
Nuuanu (Elec. Station), sw	405	13.50
Nuuanu (Luakaha), c	850	26.50
Waimanalo, ne	25	13.02
Maunawili, ne	300	19.45
Kaneohe	100	12.51
Ahuimanu, ne	350	22.43
Kahuku, n	25	11.85
Waialua	20	8.63
Wahiawa	900	....
Ewa Plantation, s	60	5.14
Waipahu	200	5.43
Moanalua	15	11.68
Laniakea (Nahuina)	1,150	15.00
Tantalus Heights	1,360	17.04
U. S. Experiment Station	350	10.69
Upper U. S. Exp. Sta. (Castle)	1,150	....
U. S. Magnetic Station	45	....
KAUAI.		
Lihue (Grove Farm), e	200	12.81
Lihue (Molokoa), e	300	13.87
Lihue (Kukaua), e	1,000	19.17
Vealia	15	....
Kealia, e	15	14.36
Kilauea, ne	325	14.14
Hanalei, n	10	27.64
Waioli	10	22.04
Haena	15	....
Waiawa	32	1.79
Eleele	200	3.83
Wahiawa	2,100	14.15
Wahiawa (Mountain)	3,000	....
Lawai	200	5.18
Lawai	450	7.97
Lawai	800	7.37
McBryde (Residence)	850	6.85
Delayed November reports.		
Wahiawa Mountain	3,000	26.70
Kealia	......	7.33
Kilauea, Kauai	......	10.70
Grove Farm (Lihue)	......	9.00

NOTE.—The letters n, s, e, w, and c show the exposure of the station relative to the winds.

Trade wind days, 17 (4 of north-northeast); normal, 16. Average force of wind during daylight, Beaufort scale, 2.3. Average cloudiness, tenths of sky, 5.2; normal, 4.4.

Approximate percentages of district rainfall as compared with normal: South Hilo, 160 per cent; North Hilo, 250 per cent; Hamakua, 400 per cent; Kohala, 330 per cent; Waimea (Hawaii), 380 per cent; Kona, 300 to 400 per cent; Kau, 140 to 300 per cent; Puna, 175 per cent; Maui, 150 to 500 per cent; Oahu, 220 per cent, except Kahuka, 420 per cent; Kauai, 320 per cent.

The month was a rainy one, and the whole year's rainfall, when published, will show surprising records. The heaviest rainfall for the month was at Puuohua, 34.84 inches; the heaviest 24-hour, 10.55, at Hanalei, Kauai, on the 11th; Nahiku (850 feet), 8.90, on the 18th.

Mean temperatures: Pepeekeo, Hilo district, 100 feet elevation, mean maximum, 75.0°; mean minimum, 68.2°; Waimea, Hawaii, 2730 elevation, 74.3° and 58.2°; Kohala, 521 elevation, 75.8° and 65.1°; Waiakoa, Kula, Maui, 2700 elevation, 73.3° and 56.6°; Puunene Mill, Maui, 200 (?) elevation, 77.0° and 65.1°; mean temperature, 69.8°; Ewa Plantation, 50 elevation,